The effect of primer cap material on ballistic toolmark evidence

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HIGHLIGHTS

- SEM-EDS analysis of primer cap materials
- *Intra*- and *Inter*- manufacturer comparison
- The material composition of a primer cap will influence the topography of the firing pin impression, and therefore the areal correlation results gained

ABSTRACT

There has recently been an increase in the research and implementation of advanced measurement techniques to ballistic toolmark identification. This has led to a shift from greyscale imaging to the acquisition of dense areal datasets. With the addition of mathematical correlation algorithms, these advanced techniques will be advantageous in criminal investigation. However, with the use of areal topography comes the addition of height point data which may differ in primer caps of varying material composition.

This study discusses the differences in the overall topography of firing pin impressions in different primer cap materials, and the effect it has on the successful correlation of ballistic toolmark evidence.

AIMS

The aims of this study are to investigate the effect of primer cap material on the topography of the firing pin impression, and to discuss the efficacy of correlating firing pin impressions imparted into varying substrate materials with differing hardness.

It is expected that differences in material properties, such as material hardness, will have an effect on the topography of the firing pin impression. This effect of material hardness means studies into whether or not toolmarks imparted on varying primer cap materials can be successfully correlated against impressions in another material are vital. Therefore, this paper will investigate this problem using advanced metrology techniques and associated algorithm-based correlation.

1 INTRODUCTION

Current trends have seen an increase in research based around advanced measurement and correlation techniques in the comparison of ballistic toolmarks. The implementation of automated systems is expected to decrease the expense of correlation through automated elimination of definite non-matching toolmarks. This will leave a much smaller database of possible matching toolmarks for the expert examiner to compare, thus decreasing the correlation time and expense of correlation [1, 2, 3, 4].

However, with the advancement of measurement capabilities comes the addition of a large amount of data regarding the topography of the surface. Where grey scale image comparison relies on pattern comparison by eye which is related to the shadow and reflection marks on a surface, areal topography and mathematical correlation also takes into account absolute height variations between the two surfaces [5].

To be able to implement advances techniques into ballistic toolmark investigation it is vital to understand the minute differences in toolmarks caused by the intrinsic variations described above. The hardness value of the substrate material, in this case the primer cap of the cartridge, will have an obvious effect on the topography of the impression. For example, a softer material used for a primer cap would potentially contain a deeper and wider firing pin impression due to the increased materials flow resulting from a higher material ductility, with the opposite effect for harder primer cap materials.

At the time of this study, there has been no research into the effect of primer cap material on the topography of firing pin impressions. Research has focussed on the striations imparted by the surface of screwdrivers, however this amounts to only two papers [6, 7]. Some research into the variability of ballistic toolmarks has been conducted, however a focus of firing pin topography differences due to cartridge material variation has not yet been conducted. De Smet et al used white-light profilometry to assess the effect of primer cap seating depth on transferred toolmarks. It was found that primer cap seating depth would influence the topography of the firing pin impression, however striae patterns within breechface marks were not affected [8].Weller et al discussed the Areal Cross Correlation Function (ACCF) results in breechface and primer shear toolmarks using consecutively manufactured Ruger pistol breechfaces. It was found that correlation results were accurate when using four different brands of ammunition, however material differences in the cartridges, or lack of, was not discussed [9].

This study will focus on the effects of primer cap material on the topography of firing pin impressions, with further work including expanding the study to encompass all ballistic toolmark evidence. This will strengthen the future of advancement measurement techniques in ballistic toolmark comparison.

2 METHODS

2.1 TEST SAMPLE

A test sample of 30 fired primer caps were acquired using a single Remington 7.62 700 'Tactical' firearm. This firearm was used due to it being readily available and compliant with the authors firearms certification clearance. It is accepted that other firearms may be more prevalent in criminal activity, it was deemed appropriate for this pilot study. Five 308 Winchester cartridges were fired per each of the six cartridge manufacturers, as detailed:

Table 1: Cartridge manufacturers used in the study

Manufacturer	Material
Winchester	Nickel
Wolf	Brass
S&B	Brass
PPU	Brass
Patrone	Brass
Hornady	Brass

2.2 Material composition

It was necessary to ascertain the material composition of each primer cap using non-destructive techniques (i.e. surfaces only) to allow for further measurements of the firing pin impressions. Therefore, Energy Dispersive X-ray Spectroscopy (EDS) attached to a Field Emission Gun Scanning Electron Microscope (FEG-SEM) was used. To ensure the method remained non-destructive, material composition was not completed at a depth below the surface.

Using the Quanta 250 FEG-SEM with a 10kV voltage, a working distance of 20.8mm and 31x magnification, three areas one primer cap per manufacturer were analysed for elemental composition using EDS analysis. This resulted in 18 intra-manufacturer measurements. The results were averaged and the standard deviation for intra-manufacturer results was calculated to gain an insight into the degree of homogeneity across the samples.

2.3 Measurement

The primer cap surface topography datasets were acquired using the Alias ballistic imaging system™. The system uses low coherent light interferometry- the analysis of the interference of superimposed non-synchronous light beams- to acquire dense areal datasets containing the areal topography of ballistic toolmarks [10].

To gain a lateral 2µm resolution from a measurement, the numerical aperture needed for the imaging optics results in an image field of 0.48x0.48mm, which is not large enough to capture the whole area of interest. Therefore, a motorised stage is used to be able to move around the area of interest and capture as many image fields as needed. These are then digitally stitched together to create the full areal topography of the area, as seen in Figure 1.

As the toolmarks such as the firing pin impressions have a height range that is also higher than can be acquired in one image field, the interferometer is able to scan in the z axis range, acquiring datasets of the focussed areas of interest before stitching to create the full topography [11, 12].

Datasets can then be exported in comma separated value (.csv) format, in which the z height for each point is mapped according to its x and y values. This data file can then be imported directly into software used for further analysis.

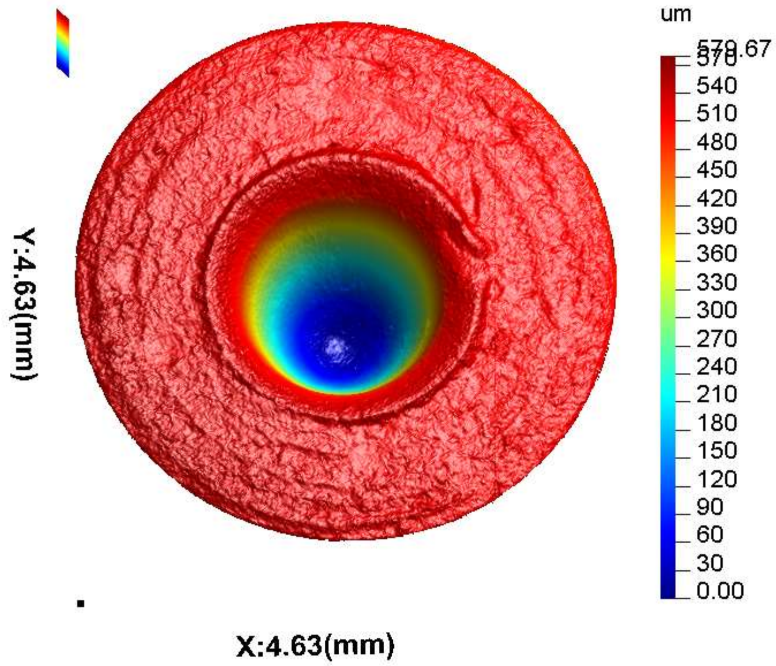


Figure 1: Example primer cap dataset

2.4 CORRELATION

The correlation of ballistic toolmarks can be tailored to the surface of interest. In this report, least squares levelling and a robust Gaussian filter with cut off lengths of 75µm-450µm were used to filter the dataset before correlation using the Areal Cross Correlation Function ($ACCF_{max}$) and Surface Difference (D_s) algorithms to ascertain the similarity between toolmarks imparted into different materials. The cut-off values used were found to be valid in previous research conducted by the author [14]. $ACCF_{max}$ was developed at NIST as a direct translation from the 2D Cross Correlation function traditionally used in signal processing [14].

The Areal Cross Correlation Function, $ACCF_{A,B}(\tau_x, \tau_y)$, for two datasets A and B is:

$$ACCF_{A,B}(\tau_x, \tau_y) = \frac{E\left(\left(A_{tx,ty} - \mu_A\right)\left(B_{tx+\tau_x, ty+\tau_y} - \mu_B\right)\right)}{\sigma_A \sigma_B}$$

1

Where μ_A and μ_B are the mean values of datasets A and B respectively. σ_A and σ_B are the standard deviation of Data A and Data B respectively.

The $ACCF_{\max}$ can then be defined as the maximal value of $ACCF_{A,B}(\tau_x, \tau_y)$:

$$ACCF_{\max} = \max\left(ACCF_{A,B}(\tau_x, \tau_y)\right)$$

2

Due to the root mean square function within the $ACCF_{max}$ algorithm, the results are not sensitive to scale. Therefore, the surface difference (D_s) algorithm is used to be able to highlight a match that has a large-scale difference and should be discarded [13].

$$D_s = \frac{\sum((Z_A(x,y) - \bar{Z}_A) - (Z_B(x,y) - \bar{Z}_B))^2}{\sum x,y\,(Z_A\,(x,y) - \bar{Z}_A)^2}$$

2.5 Processing of salient data for correlation

Before correlation each dataset must be subject to pre-processing, to remove: i) any fine scale optical noise from the surface data, ii) the form of the surface that may mask toolmarks in correlation and iii) any differences in tilt through slight differences in measurement angle. To remove any differences in tilt angle, a least squares levelling technique is first applied to the primer cap data.

As previously mentioned, the pre-processing used depends on the surface, and in the case of firing pin impressions a robust Gaussian filter with cut off values of 75µm and 450µm is used. This filtering window conveniently removes the fins scale optical anomalies and the surface form error leaving only surface texture marks at the scale of the relevant tool marks [14, 15]. Figure 2 represents the original primer cap dataset (left) and the filtered version (right)

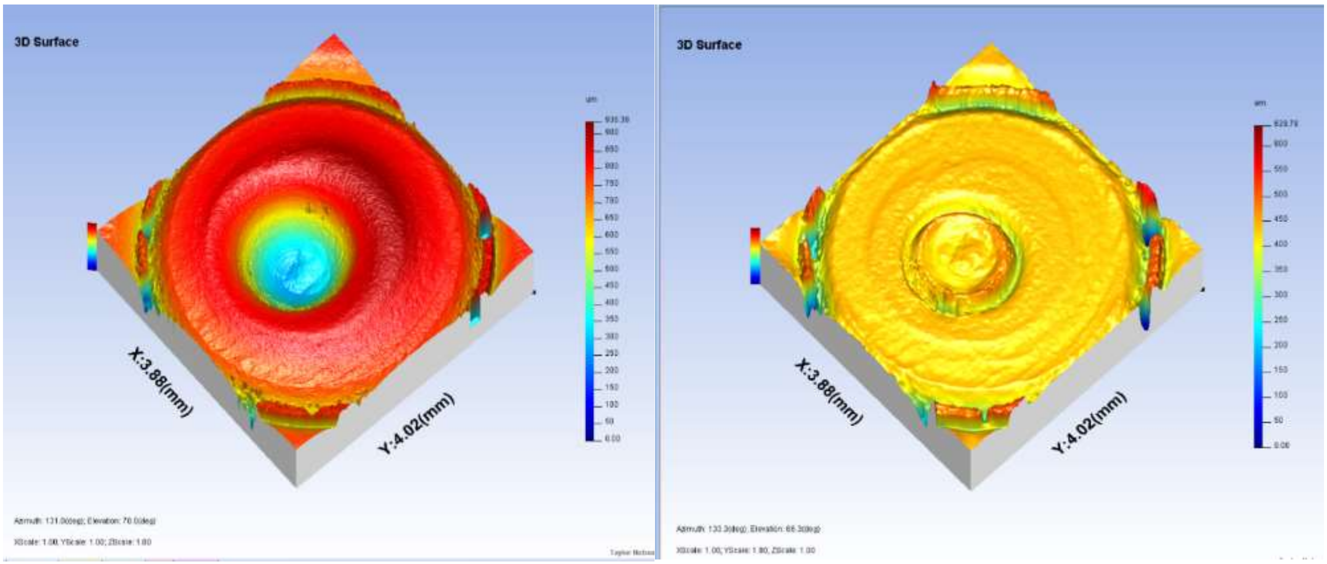


Figure 2: Image showing primer cap dataset before pre-processing (left) and after (right)

Once pre-processing is completed, the .csv files are then imported into a MATLAB toolbox, which firstly translates datasets from the original cartesian coordinates to polar coordinates before performing the $ACCF_{max}$ and D_s correlation algorithms. Using polar coordinates leads to a rotationally invariant dataset, which decreases the correlation time due to less shifts between the superimposed datasets [13].

The toolbox allows the user to select the correlation area circle from the dataset. In the case of firing pin impressions, a circle radius of 0.35mm is used which allows the area of correlation to relate to the firing pin impression [13].

2.6 VOLUME PARAMETER AND FORM ANALYSIS

Unfiltered datasets of each fired primer cap were exported into Surfstand™ software [15]. Using this software each dataset was first levelled using the least squares method before a high pass robust Gaussian filter of 25µm was used to remove any optical noise from the dataset while keeping the original form of the impression intact. This allowed material flow and impression depth to be studied in more detail

Volume parameters were calculated using the standard material ratios for volume analysis, in which the top 10% of height values are designated as peak values and the lowest 20% are designated as valley values, those values in between are termed the core volume values, as shown in Figure 3. [16, 17]. Volume parameters are then calculated as per Figure 3. Where Vmp = the peak material volume, Vmc = the core material volume, Vvc = the core void volume and Vvv = the valley void volume. It is considered that materials displaying more material flow (lower hardness) should have higher volume parameter values.

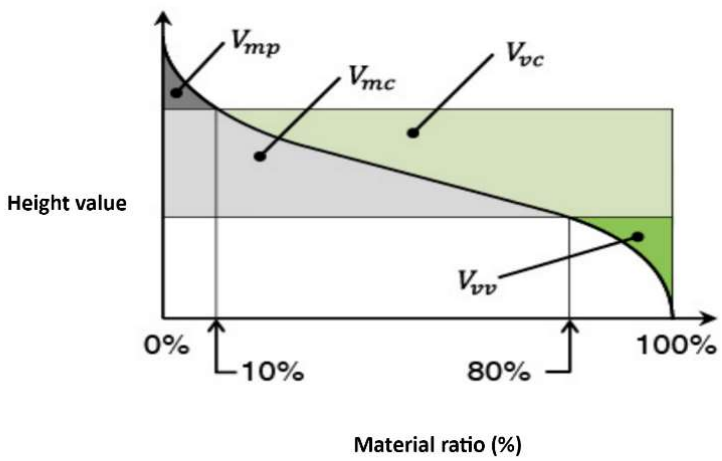


Figure 3: Volume parameters based on height point values [16]

For the present work the areal parameters calculated for each primer cap only included: Vmp (peak material volume) and Vvv (valley void volume). These volume parameters were used to demonstrate a difference in the overall topography of the firing pin impression, where expected differences included the level of flowback in the firing pin impression and valley volume created by the firing pin. (Figure 4)

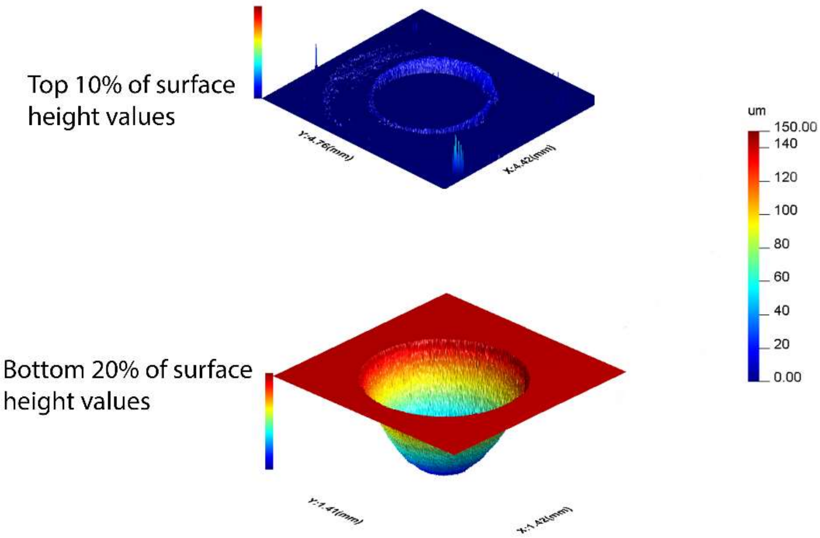


Figure 4: Winchester primer cap sectioned into the top 10% and bottom 20% of surface height data

The software was also used to generate 2D profiles across the surface topography of the primer cap. A centre point is manually selected by the user, for this study the centre of the firing pin impression was used. From this centre point two lines are generated in the x and y directions. The measurement points corresponding to these lines are extracted from the dataset, resulting in two 2D profiles of the cross sections of the datasets (Figure 5).

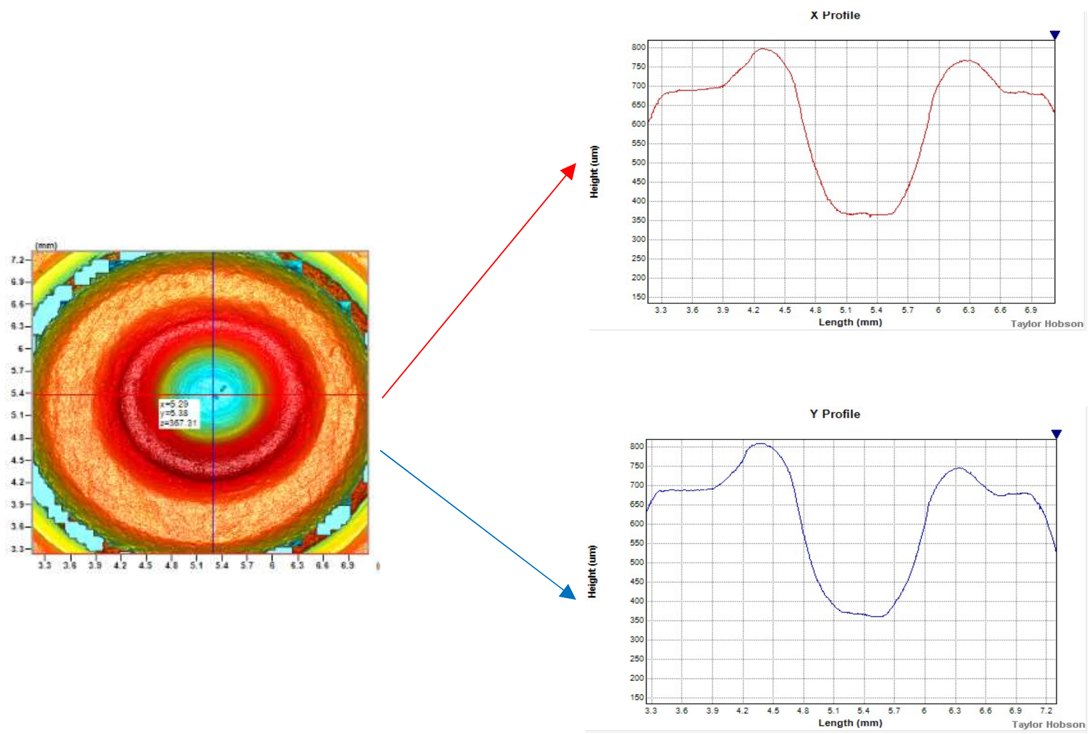


Figure 5: Schematic of the 2D profile extraction. The resultant 2D profiles (right) can be seen as lines on the original dataset (left)

3 RESULTS

3.1 Material composition

Material composition was analysed across three points on each primer cap. Results were then averaged for each intra-manufacturer group. Figure 6 graphically represents average elemental composition ± 1 standard deviation.

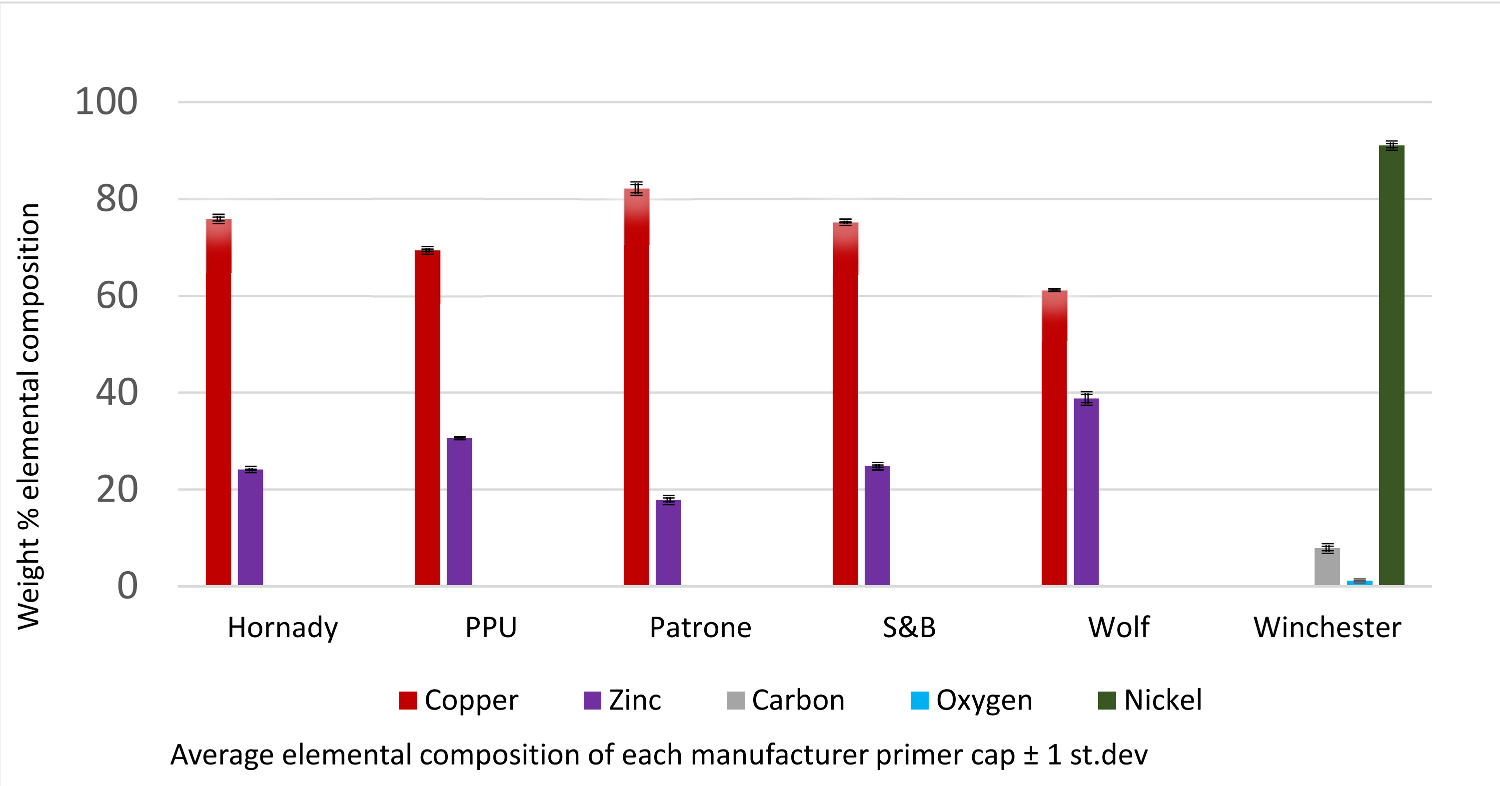


Figure 6: Graph of average elemental composition per each manufacturer ± 1 standard deviation.

3.2 Correlation

In intra-manufacturer tests, 10 correlations were completed as correlations between a single primer cap to itself have been discounted from correlation results. This results in a total of 60 intra-manufacturer correlations. As a total of six manufacturers were used this resulted in 375 inter-manufacturer correlations.

A total of 435 individual correlations were calculated during the study. For each group of correlations, i.e. manufacturer vs manufacturer, the correlations have been averaged and a 95% confidence limit calculated. Figure 7 graphically represents correlation results within the same manufacturer and Figure 8 represents correlations where there is a difference in manufacturer.

It is possible in correlation to acquire a D_s value which is over 100. In such cases, the result is regarded as a false match as the scale differences between the two surfaces are too significant to regard the result as a true match, based on previous research by the author [14]. Correlation of the samples used above however did not produce any D_s values of over 100. This indicates that a scale difference in toolmarks due to material composition differences in primer caps does not produce false matches.

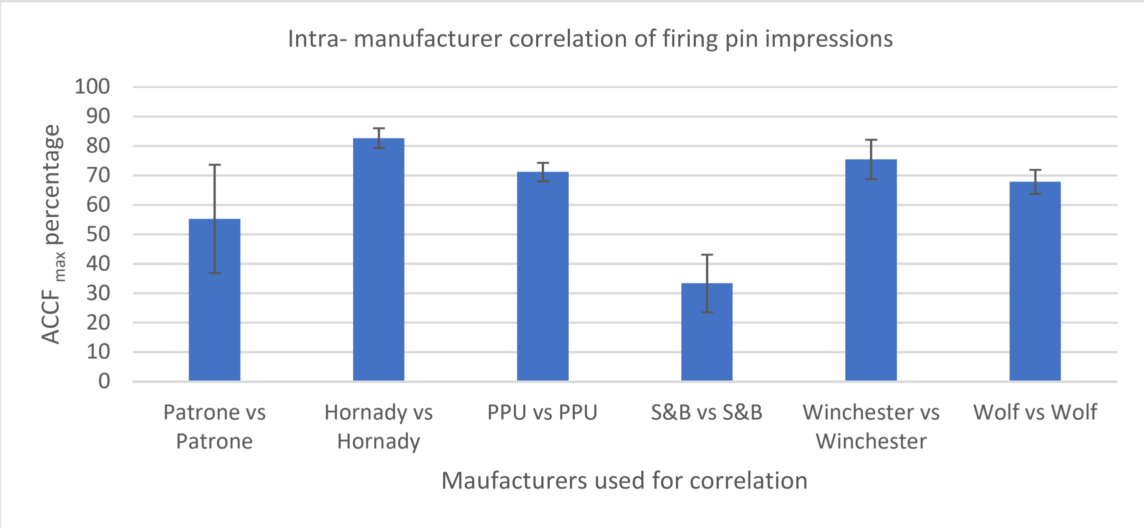


Figure 7: Intra-manufacturer correlation results

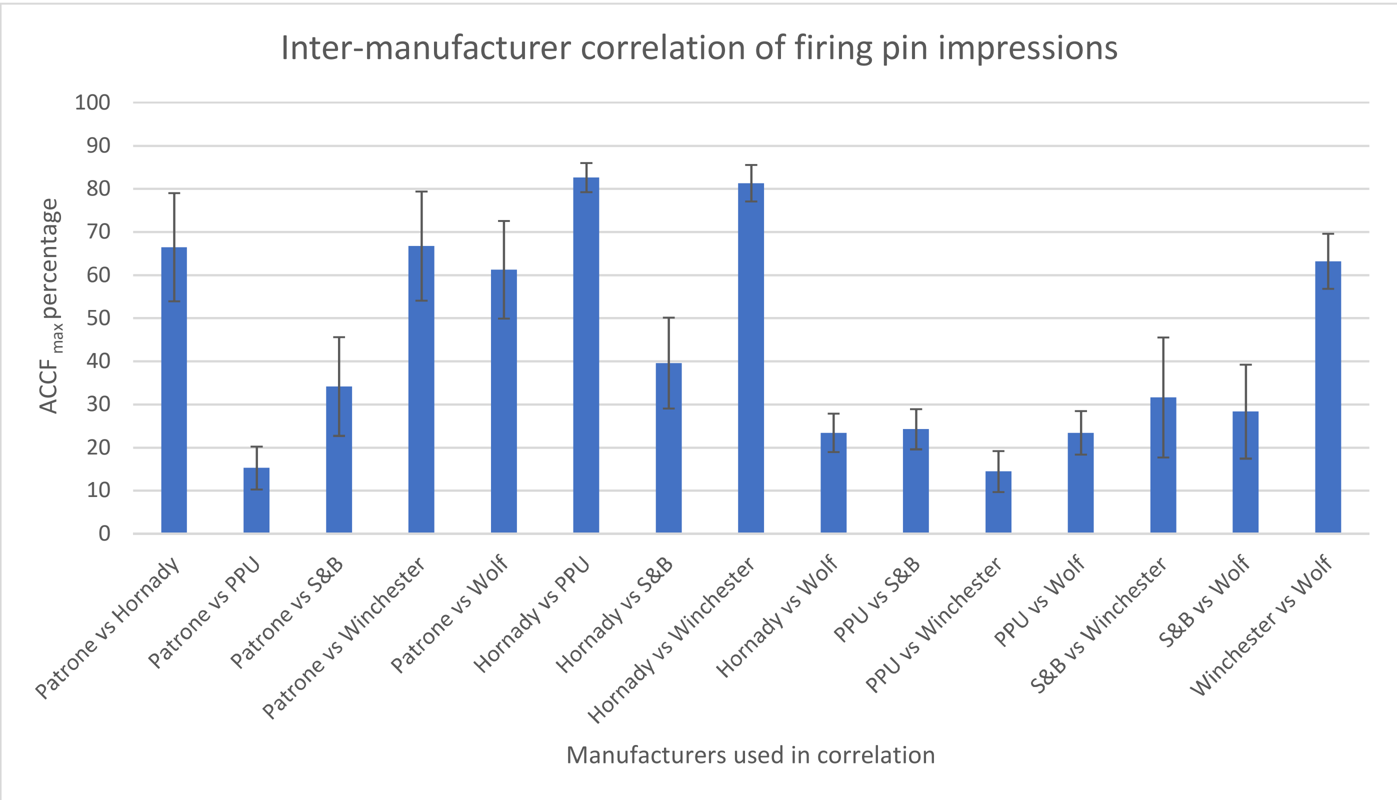


Figure 8: Inter-manufacturer correlation results

3.3 VOLUME PARAMETERS

Vmp (Figure 9) and Vvv values (Figure 10) were plotted as an average intra-manufacturer result, with error bars representing 95% confidence limits.

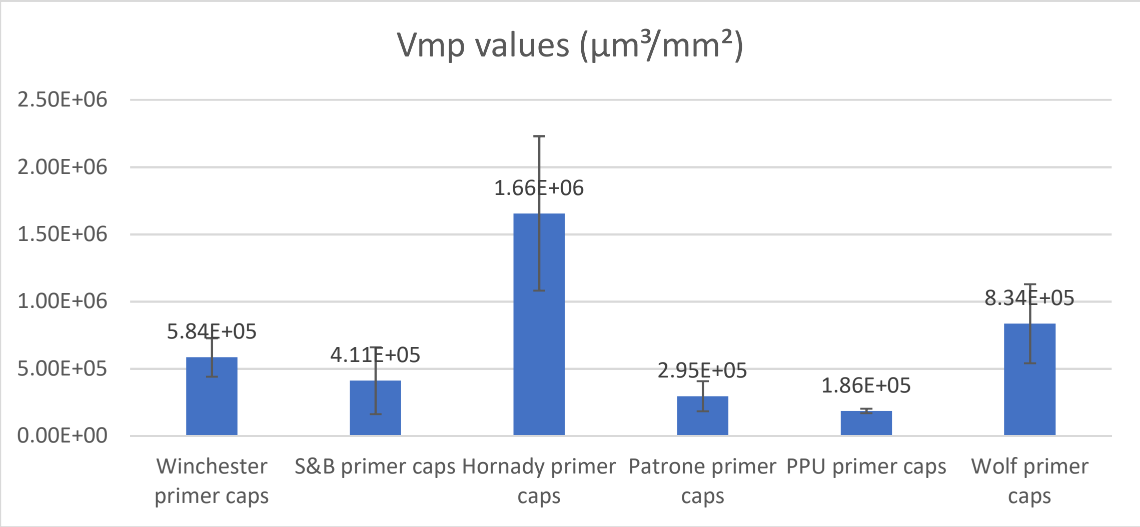


Figure 9: Graph of Vmp values for primer cap topography.

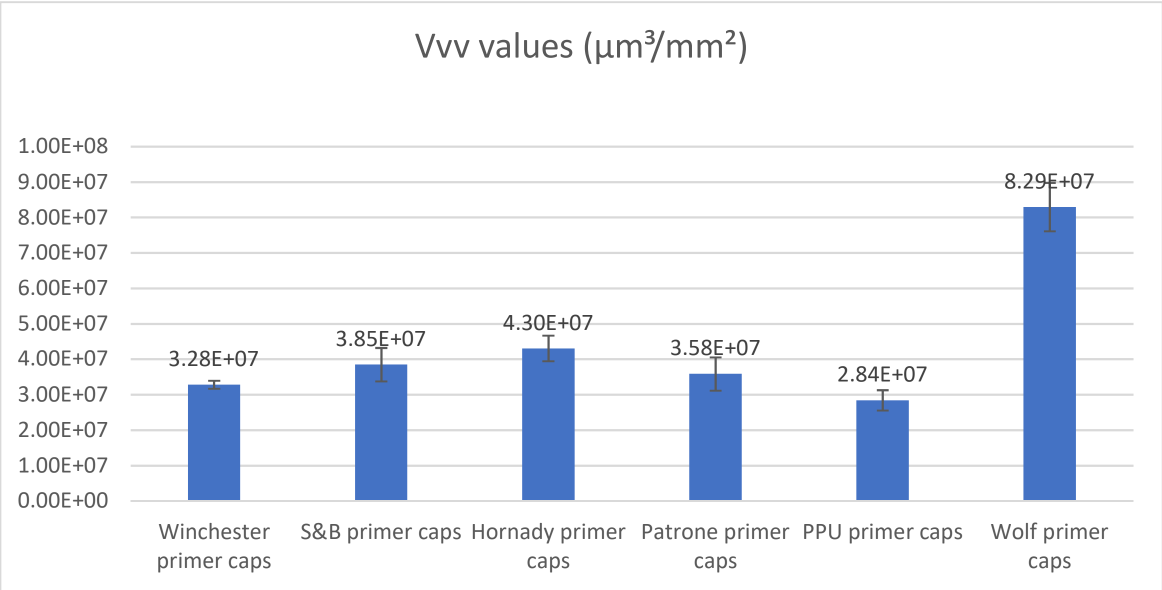
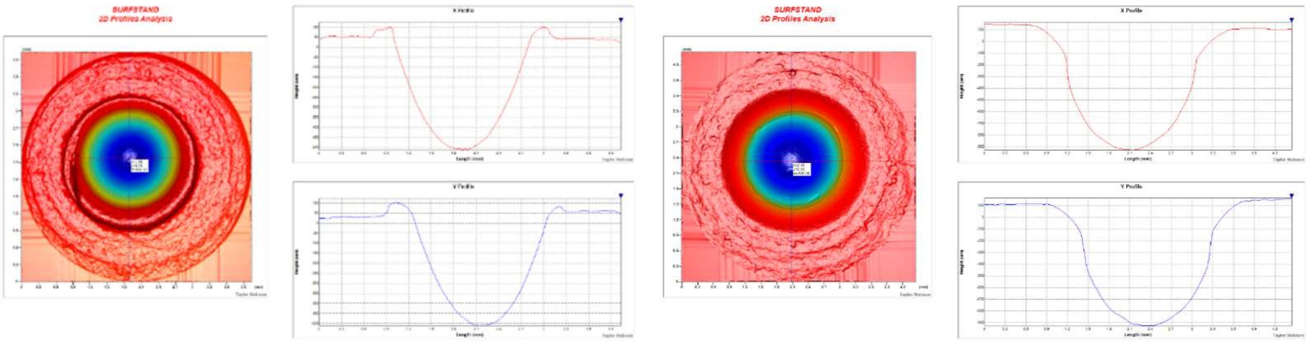


Figure 10: Graph of Vvv values for primer cap topography

3.4 2D PROFILES OF IMPRESSIONS

Figure 11 shows an example of the visual difference in 2D profiles extracted from firing pin topography. It can be seen that more flowback is present in the Hornady primer cap, while the Wolf primer cap has a noticeably wider firing pin impression.



a) Hornady primer cap b) Wolf primer cap

Figure 11: Examples of 2D profiles extracted from a Hornady primer cap (a) and a Wolf primer cap (b)

4 DISCUSSION

4.1 MATERIAL COMPOSITION

Elemental analysis of the primer cap surface shows that there can be a significant difference in brass composition in inter-manufacturer comparison. Zinc composition ranged from 17.85% in Patrone cartridges to 38.8% in Wolf cartridges. Where there is a significant difference in brass composition it can be assumed that there will also be a significant difference in material hardness, i.e. the more zinc the harder the material and therefore topography of toolmarks imparted will be dissimilar. As the material composition was tested on the surface of the primer cap, further research by the authors will determine if these results are corroborated when testing material composition under the surface and with a direct surface hardness measurement.

It was also found that the standard deviation of elemental composition would vary between cartridge manufacturers, with the largest deviation found in Patrone primer caps. This indicates that a dissimilarity in toolmarks due to material hardness in impressions found in primer caps of the same manufacturer may be observed. It should be noted that direct hardness measurement of the primer materials are not reported in the present case. This was due to the fact that direct measurements using a Vickers Microhardness machine on the cartridge cases caused slight distortion of the case and hence errors in the results. To further this investigation, more cartridge manufacturers and more repeats of each manufacturer will be included.

4.2 CORRELATION

The correlation results show that in intra-manufacturer correlation, there are some variations that could lead to a false negative result in Patrone and S&B primer caps. Correlation results of Patrone primer average 55% with a lower confidence limit of 37%. Correlation values in S&B primer caps average 33% with a lower confidence limit of 22%. In these cases, it would be understandable for a false negative result to be recorded due to percentage match results being low. This indicates a physical variation at the time of firing the cartridge, which may be due to material variability between cartridges.

Where there is a higher spread in the percentage of alloying elements within the brass primer caps, correlation has been affected. Patrone was found to have the largest deviation in intra-manufacturer brass composition. In the $ACCF_{max}$ correlation results, it can be seen that Patrone also has the largest 95% confidence limits. This indicates that correlation can be affected by material composition even when the same cartridge manufacturer is used for correlation.

Correlation results between S&B primer caps were also found to be poor, with an average value of 33% and a large confidence limit value. As there was little spread in alloying element percentage, it is believed that correlation may also be influenced by other factors which will be discussed in the following sections.

A higher correlation was found in intra- correlation for Hornady, PPU, Winchester and Wolf primer caps. As elemental composition had little variance between primer caps, this further demonstrates the effect of elemental composition on correlation results.

When correlating inter-manufacturer primer caps, it was shown that there is a large variance in results. Correlation ranged from 14% (PPU vs Winchester) to 83% (Hornady vs PPU), and confidence limits remained high in each combination of manufacturer. These results illustrate that there is a significant effect on correlation where elemental composition is not similar, and indicates that inter-manufacturer areal correlation should be treated with a degree of added caution as there is likely to be a physical difference in the firing pin impression due to variance in material hardness. Further work will include determining whether the same effect on correlation due to material composition can also been seen in breechface and extractor marks.

4.3 VOLUME PARAMETERS

Volume parameter results show that firing pin impression imparted in Hornady primer caps result in the largest flowback, indicated by significantly larger Vmp values. As Hornady primer caps have one of the lowest percentages of Zinc in the brass composition, it can be shown that lower zinc levels result in a higher plastic material flow, and hence a larger flowback in firing pin impressions. However, Hornady correlation results were high in intra-manufacturer correlation, indicating that flowback does not have a noticeable effect of correlation results. As the bottom surface is used for correlation in firing pin impressions, this is not unexpected. However, it is expected variation in flowback will have an effect on breechface impression correlation which will be studied in further work.

Wolf primer caps were found to have a significantly larger Vvv value in firing pin impressions than other cartridge manufacturers, and had the highest percentage of Zinc in the brass composition. Wolf correlation results were also slightly lower than those found in Hornady correlation results. This demonstrates that higher Zn vales in primer caps results in a larger volume in firing pin impressions, which may influence correlation results.

4.4 2D PROFILE: VISUAL COMPARISON

Visual comparison of 2D profiles support the results acquired in volume parameter analysis. Profiles extracted from Hornady primer caps have an obvious flowback around the firing pin impression. Visual comparison of 2D profiles extracted from Wolf primer caps shows a significantly larger firing pin impression volume than seen in primer caps from other manufacturers, thus corroborating the volume parameter results.

5 CONCLUSIONS

From this study it can be concluded that the material composition of primer cap will have an effect on the areal topography of the firing pin impression, and therefore the correlation results gained. As the result is a physical difference in the topography of the impression, it is believed that filtering of the dataset alone may be able to sufficiently remove differences in the impression. Therefore, it can be recommended that in toolmark comparison for case work, care should be taken when correlating areal impressions with a dissimilar substrate material.

Some findings, for example in the case of S&B primer caps, have low correlation results which cannot be solely attributed to material composition. There are several variables that have not been considered in this study which could be affecting correlation results, including material thickness, primer cap angle, and weight and composition of propellant. Therefore, this study should be expanded to include all variables to determine how significant each variable is with regards to correlation efficacy.

6 FUTURE WORK

The scope of this study is currently being expanded to include more manufacturers and more repeats per manufacturer. The study of toolmarks will also be expanded to include bullets, breech face impressions and extractor impressions. Direct material hardness values will be made using cross section metallurgical techniques. The differences in propellant composition and material thickness of bullets, cartridge cases and primer caps will also be studied.

ACKNOWLEDGEMENTS

The author gratefully acknowledges the UK's Engineering and Physical Sciences Research Council (EPSRC) funding of the EPSRC Centre for Innovative Manufacturing in Advanced Metrology (Grant Ref: EP/I033424/1).

The research would not have been possible without the support of Forensic Pathways ltd.

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